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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R.§ 1.53(b))

Attorney Docket No.	1-50
First Inventor or Application Identifier	KOMURA et al.
Title	METHOD FOR MEASURING THICKNESS OF OXIDE FILM
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

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1. [X] * Fee Transmittal Form (e.g., PTO/SB/17) *(Submit an original and a duplicate for fee processing)*
2. [X] Specification [Total Pages 24]
   - -Descriptive title of the Invention
   - -Cross Reference to Related Applications
   - -Background of the Invention
   - -Summary of the Invention
   - -Brief Description of the Drawings
   - -Detailed Description of the Preferred Embodiment
   - -Claims
   - -Abstract of the Disclosure
3. [X] Drawing(s) *(35 U.S.C. 113)* [Total Sheets 5]
4. Oath or Declaration [Total Sheets 4]
   - a. [X] Newly executed (original or copy)
   - b. [ ] Copy from a prior application (37 C.F.R. § 1.63 (d)) *(for continuation/divisional with Box 16 completed)*
     - i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

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5. [ ] Microfiche Computer Program *(Appendix)*
6. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   - a. [ ] Computer Readable Copy
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ACCOMPANYING APPLICATION PARTS

7. [X] Assignment Papers (cover sheet & document(s))
8. [ ] 37 C.F.R.§ 3.73(b) Statement *(when there is an assignee)* [X] Power of Attorney
9. [ ] English Translation Document *(if applicable)*
10. [X] Information Disclosure Statement (IDS)/PTO-1449 [X] Copies of IDS Citations
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FILING CERTIFICATE

Applicant: KOMURA et al.

For: METHOD FOR MEASURING THICKNESS OF OXIDE FILM

Docket: 1-50

Attorney: David G. Posz

Date of Deposit: July 13, 2000

I hereby certify that this certificate and the following documents are being hand-delivered to, and deposited on the above-indicated date with, Office of Initial Patent Examination at the United States Patent Office, and are addressed to the Commissioner of Patents and Trademarks/Assistant Commissioner for Patents, Washington, D.C., 20231:

- return receipt postcard;
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- transmittal form (2 copies);
- fee calculation form (2 copies);
- 24 page specification including 22 numbered claims;
- 5 sheets of formal drawings;
- executed declaration and power of attorney;
- assignment and recordation cover sheet;
- IDS with PTO-1449 form and 2 references; and
- 1 copy of a certified priority document (JP 11-203562).

David G. Posz

METHOD FOR MEASURING THICKNESS OF OXIDE FILM

CROSS REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of Japanese Patent Application No. 11-203562 filed on July 16, 1999, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method for measuring a thickness of an oxide film formed on a substrate, which is suitably applied for evaluating a thickness of a transistor gate oxide film.

2. Description of the Related Art

Recently, a thickness of a MOS transistor gate oxide film in an LSI has been thinned to be less than 100Å to comply with requirements for an improved integration density and an increased speed. Therefore, it has been required and examined to measure the thinned gate oxide film accurately in view of reducing a measurement error. Widely known methods for measuring a thickness of a gate oxide film are an ellipsometry utilizing a polarization analysis, a nano-spectroscopy utilizing an optical interference method, and the like ("University Course of Electricity Institute, Electronic Material Engineering", P. 228-231, written by Institute of Electricity Communicational Education, and "Applied Physics Selection, 3. Thin Film", P. 200 to 203, written by S. Kanbara and H. Fujiwara). In the ellipsometry, light is irradiated on the gate oxide film by an optical instrument to detect a refractive

index and an absorption coefficient, and the thickness of the gate oxide film is measured based on the refractive index and the absorption coefficient.

SUMMARY OF THE INVENTION

However, when the thickness of the gate oxide film was measured by the conventional optical instrument, large variations beyond measurement errors of the optical instrument occurred. The large variations make measurement and control of the gate oxide film thickness inaccurate and difficult.

The present invention has been made in view of the above problem. An object of the present invention is to provide a method for measuring a thickness of an insulating film. Another object of the present invention is to control and evaluate an insulating film easily.

According to a first aspect of the present invention, a thickness of an oxide film is measured by controlling a left period of time for leaving the oxide film from the formation of the oxide film to the measurement of the thickness. As a result, the thickness can be measured accurately. The measured thickness may be corrected in accordance with the left period of time.

According to a second aspect of the present invention, a thickness of an oxide film is measured after washing a surface of the oxide film. The washing of the oxide film removes deposits from the surface of the oxide film, resulting in accurate measurement of the thickness of the oxide film. The left period of time for leaving the oxide film from the washing to the

measurement of the thickness can be controlled to more precisely measure the thickness.

When the method for measuring the thickness of the oxide film according to the present invention is performed on the way of manufacturing a semiconductor device, a defective can be found out on the way of manufacture by determining whether the thickness of the oxide film falls in a desirable range or not. A succeeding step is performed when the thickness falls in the desirable range.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and features of the present invention will become more readily apparent from a better understanding of the preferred embodiments described below with reference to the following drawings, in which;

FIGS. 1A to 1C are cross-sectional views showing manufacturing steps for a MOS transistor to which a method for measuring a thickness of a gate oxide film is applied in a first preferred embodiment;

FIGS. 2A to 2C are cross-sectional views showing manufacturing steps for the MOS transistor, following the step shown in FIG. 1C;

FIG. 3 is a graph showing a relation between an apparent thickness of the gate oxide film and a left period of time elapsed from the formation of the gate oxide film;

FIG. 4 is a graph showing thicknesses of the gate oxide film, corrected by an approximate formula, in a second preferred embodiment;

FIG. 5 is a graph showing a relation between a thickness of the gate oxide film determined by the approximated formula, and a thickness of the gate oxide film calculated based on a capacitance;

FIG. 6A is a graph showing a change in thickness of the gate oxide film before and after washing is performed using a mixed solution of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) in a third preferred embodiment; and

FIG. 6B is a graph showing a change in thickness of the gate oxide film before and after washing is performed using a mixed solution of hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2) in the third embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(First Embodiment)

In a first preferred embodiment, a method for measuring an oxide film thickness according to the present invention is applied to a manufacturing process for a MOS transistor. Specifically, in a manufacture line for a product including a MOS transistor, a thickness of an oxide film formed therein is measured. If the thickness falls in a desirable range, the next step is performed. If the thickness is out of the range, the produce is removed as a defective.

The method for measuring the thickness of the oxide film is specifically explained referring to FIGS. 1A-1C and 2A-2C below. First, as shown in FIG. 1A, a thermal oxide film 2 is formed on a silicon substrate 1, and a photolithography step and an ion

implantation step are successively performed to form an N type well region 3 and a P type well region 4 in the substrate 1. For instance, phosphorous is ion-implanted at approximately 1×10^{13} atmos/cm^2 to form the N type well region 3, and boron is ion-implanted at approximately 3.4×10^{13} atmos/cm^2 to form the P type well region 4.

Next, after a heat treatment called as drive-in is performed at 1170℃, as shown in FIG. 1B, a nitride film (Si_3N_4) 5 is deposited on the silicon substrate 1 by a low pressure CVD method. After that, the nitride film 5 is patterned. After a resist is disposed and patterned by a photolithography step, boron is ion-implanted, for instance, at 7×10^{13} atmos/cm^2 into a region where a channel stopper 6 is to be formed. Then, annealing is performed in N_2 atmosphere to form the channel stopper 6.

As shown in FIG. 1C, a LOCOS oxide film 7 is formed by thermal oxidation for element isolation at a boundary portion between the N type well region 3 and the P type well region 4. The nitride film 5 and the oxide film region other than the LOCOS oxide film 7 are removed. As shown in FIG. 2A, a gate oxide film 8 is further formed by thermal oxidation. The method for measuring the thickness of the oxide film according to the present invention is applied to this gate oxide film 8.

Specifically, the thickness of the gate oxide film 8 is measured by an ellipsometer utilizing a polarization analysis. That is, light is irradiated on the gate oxide film 8 and a refractive index and an absorption coefficient of the gate oxide film 8 are detected to determine the thickness of the gate oxide film 8.

This measurement of the thickness is performed when a specific period of time is elapsed from the time when the gate oxide film 8 is formed.

This is because it is found that an apparent thickness of the oxide film measured by an optical instrument increases gradually after the oxide film is formed on the substrate. FIG. 3 shows a relation between a change in apparent thickness of the oxide film and a left period of time from the time immediately after the oxide film is formed to the time for measuring the thickness. As shown in the figure, the apparent thickness of the oxide film changes in accordance with the left period of time after the oxide film is formed. The longer the left period of time becomes, the larger the thickness of the oxide film becomes apparently. This phenomenon is considered as follows.

As described above, the thickness of the oxide film is determined based on the refractive index and the absorption coefficient detected by light irradiated on the oxide film. That is, the thickness of the oxide film is measured based on the change in light incident on the oxide film. Therefore, if deposits exist on the surface of the oxide film to influence the refractive index and the like, the thickness of the oxide film can be measured as if it is increased.

To confirm this point, the surface of the oxide film, a thickness of which was increased apparently, was washed, and then the thickness of the oxide film was measured again. As a result, the thickness of the oxide film was returned to that measured immediately after the oxide film was formed. This reveals that

deposits (for instance, water and carbon in the air) attached to the surface of the oxide film can apparently increase the thickness of the oxide film.

Incidentally, after the surface of the oxide film was washed, the oxide film was left for a specific period of time again, and the change in thickness of the oxide film was measured with respect to the left period of time. Consequently, substantially the same experimental result as that shown in FIG. 3 was obtained. This result supports that water, carbon, and the like in the air are attached to the surface of the oxide film to apparently increase the thickness of the oxide film when the oxide film is left.

In view of the points described above, in the present embodiment, the time for measuring the thickness of the gate oxide film 8 is controlled, and the thickness of the gate oxide film 8 is measured within a specific period of time elapsed after the gate oxide film 8 is formed. Accordingly, the thickness of the gate oxide film 8 can be measured accurately before it is increased apparently.

The shorter the period of time for measuring the thickness is, the more the thickness of the gate oxide film is measured accurately. The period of time for measurement may be determined as follows.

For instance, an allowable thickness variation with respect to latitude (specification) for process control can be calculated to determine the period of time for measurement. The thickness variation in the process is calculated by a formula of:

$$\sqrt{S^2+T^2} \leq U \qquad \ldots\ldots(1)$$

where S is a variation in thickness of the gate oxide film, T is a change-variation in thickness of the gate oxide film according to the left period of time, and U is a specification latitude for the process control. The variation is calculated at 3σ. The variation S is produced when the gate oxide film is formed.

The width of the variation T that fulfills the formula (1) can determine the specific period of time for measuring the thickness based on the experimental result. The width of variation may be determined using an approximate formula that is explained in a second embodiment below.

Accordingly, after the thickness of the gate oxide film is measured, the next step is carried out when the thickness falls in a desirable range. If the thickness is out of the range, the product is removed from the manufacture line. Thus, the thickness of the gate oxide film 8 can be measured accurately by controlling the period of time for the measurement such that the measurement is performed in a short time from the formation of the gate oxide film 8. By performing the measurement of the thickness in the present embodiment, defectives can be found out on the way of manufacture with high accuracy, resulting in quick feedback for process improvement and stable yield.

As to the product fit in the thickness, as shown in FIG. 2A, a gate electrode 9 is formed and patterned on the gate oxide film 8. Successively, as shown in FIG. 2B, after a source 10 and a drain 11 are formed at both sides of the gate electrode 9, a CVD oxide film 12 is formed on the surface of the silicon substrate 1 to cover the gate electrode 9. After a reflow treatment is

performed, contact holes 12a are formed in the CVD oxide film 12. An electrical wiring pattern 13 is then disposed not only on the CVD oxide film 12 but in the contact holes 12a, and is covered by a protective film not shown. As a result, the MOS transistor is completed.

(Second Embodiment)

In a second preferred embodiment, a thickness of an oxide film, which has been measured apparently, is corrected so that an accurate thickness of the oxide film is obtained. An object to which the method for measuring the thickness of the oxide film is applied in the second embodiment is substantially the same as the MOS transistor in the first embodiment. The process for checking product defectives based on the measured thickness of the oxide film is also substantially the same as that in the first embodiment. Mainly, the correction of the thickness is explained below.

As described above, when the gate oxide film 8 is left after its formation, the relation between the apparent thickness of the gate oxide film and the left period of time is as shown in FIG. 3. An increase in the apparent thickness of the gate oxide film is represented by an approximate formula of:

$$y = a \cdot \ln(t) + b \qquad \ldots\ldots(2)$$

where $t \geq 1$, and an unit of y is Å.

In the formula (2), "a" and "b" are constants, and "t" is a left period of time elapsed from the formation of the gate oxide film 8 to the measurement of the thickness. The constant a is determined by atmosphere (temperature, moisture) around a wafer

disposed within a clean room, or the like, and was in a range of approximately 0.5 to 1.5 when it was measured in practice. The constant b is a thickness of the oxide film measured immediately after the gate oxide film 8 is formed (when t = 1 min).

Incidentally, if the left period of time t was set to be zero in the formula (2), the thickness of the gate oxide film calculated by the formula (2) is 0Å. This means that the gate oxide film 8 does not exist. Therefore, the left period of time t cannot be set to be less than 1 min when the thickness is measured immediately after the gate oxide film is formed. In practice, the initial thickness of the gate oxide film 8 is measured after the wafer is taken out of an apparatus for forming the oxide film 8. Because of this, approximately 1 min or more is required to measure the initial thickness of the gate oxide film 8 from the formation of the gate oxide film 8. Therefore, the approximate formula (2) meets the practical use.

Accordingly, the apparent increase in thickness of the gate oxide film 8 is approximated by the formula (2), and calculated in accordance with the left period of time after the formation of the gate oxide film 8. The thickness of the gate oxide film can be corrected by subtracting the apparent increase in thickness from the measured apparent thickness of the gate oxide film. Thus, the left period of time is controlled after the gate oxide film 8 is formed, and the apparent thickness of the gate oxide film is corrected by the approximate formula (2). Consequently, the accurate thickness of the gate oxide can be detected.

FIG. 4 shows variations in thickness of the gate oxide film,

quantified by the approximate formula (2) for reference. The result shown in FIG. 4 was obtained by leaving plural samples (samples A-J) for various periods of time, measuring the thickness of the gate oxide film in each sample by an ellipsometer, and correcting the measured result by the formula (2). In the figure, a broken line indicates the measured apparent thicknesses, and a solid line indicates the thicknesses of the gate oxide film after correction. Each left period of time for each sample is shown above each alphabetical reference.

As shown in the figure, the measured thickness has large variations. As opposed to this, the thickness after correction has significantly decreased variations. This implies that, when the correction is not performed by the approximate formula, the measured thickness is accompanied by large variations regardless of its actual thickness falling in the desirable range. In such a case, the thickness of the gate oxide film might be determined to be out of the range erroneously. The correction of the gate oxide film thickness using the formula (2) can prevent such erroneous determination.

Further, reliability of the gate oxide film thickness corrected by the approximate formula was evaluated while being compared with the gate oxide film thickness that was estimated by a capacitance (capacitance produced between the gate electrode and the silicon substrate) after the product was manufactured. The comparing result is shown in FIG. 5. The thicknesses measured by the ellipsometer and not corrected, i.e., the thicknesses before correction, are also plotted in the figure for reference.

As shown in the figure, the thickness of the gate oxide film corrected by the approximate formula approximately corresponds to that obtained by the capacitance, and has a significant correlation therewith. On the other hand, the thickness of the gate oxide film before correction has no relation with that obtained by the capacitance. Thus, it is confirmed that the correction using the approximate formula can determine the thickness of the gate oxide film with high reliability and high accuracy.

(Third Embodiment)

As described above, deposits on the surface of the gate oxide film 8 can cause variations in apparent thickness of the film 8. Therefore, in a third preferred embodiment, deposits are removed from the surface of the gate oxide film 8 so that the thickness of the film 8 can be measured accurately. An object to which the present embodiment is applied is substantially the same as the MOS transistor as in the first embodiment, and the method for checking product defectives based on the measured thickness of the gate oxide film is also substantially the same as that in the first embodiment. Mainly explained below is a method for removing deposits from the surface of the gate oxide film 8.

First, the gate oxide film 8 is formed on the silicon substrate 1 by performing the steps substantially the same as those in the first embodiment. Then, immediately before the thickness of the gate oxide film is measured, the surface of the gate oxide film 8 is washed by a washing solution so that deposits are removed

from the surface. Specifically, the wafer is immersed into a washing solution (mixed solution) of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2), so that deposits are removed from the wafer. After that, the thickness of the gate oxide film is measured. The thickness of the gate oxide film can be measured without being affected by the deposits, resulting in accurate measurement of the thickness.

FIG. 6A shows thicknesses of the gate oxide film measured before and after the removal of deposits. Specifically, the thickness of the gate oxide film was measured after 49 min and 16067 min were respectively elapsed from the formation of the gate oxide film 8, and after 50 min was elapsed from the washing using the mixed solution of H_2SO_4 and H_2O_2. The results are shown in FIG. 6A.

As shown in the figure, the gate oxide film, which is left for a long period of time after its formation, has an apparently increased thickness, as compared to that immediately after the gate oxide film is formed (when left period of time is 49 min). As opposed to this, the washing using the mixed solution of H_2SO_4 and H_2O_2 can return the measured thickness of the gate oxide film 8 to approximately its initial value where the oxide film 8 is not left for a long period of time. The experimental results also reveal that the thickness of the gate oxide film 8 can be measured accurately by removing deposits from the surface of the gate oxide film 8 immediately before the thickness is measured.

Incidentally, after the wafer was left for a specific period of time after the washing step was performed, the thickness of

the gate oxide film was measured again. The thickness of the gate oxide film was increased in a similar relation to that increased by being left before the washing step was performed. This result supports that the increase in the apparent thickness of the gate oxide film is caused by deposits of matters, which are contained in the air, on the surface of the gate oxide film. The deposits can change slightly a refractive index, and the like.

Thus, according to the present embodiment, the thickness of the gate oxide film can be measured accurately without being affected by deposits, by removing the deposits from the surface of the gate oxide film 8. In addition, in the present embodiment, even when the left period of time of the wafer before washing is not known, the thickness of the gate oxide film can be measured accurately by controlling the left period of time after washing.

Incidentally, as described above, since the apparent thickness of the gate oxide film is increased after washing, the thickness should be measured in a specific period of time after washing, as in the first embodiment. In the present embodiment, although deposits are removed by the washing using the mixed solution of H_2SO_4 and H_2O_2, other washing solutions such as a mixed solution of hydrochloric acid (HCl) and H_2O_2 (HPM solution) may be used in place of the mixed solution of H_2SO_4 and H_2O_2.

FIG. 6B shows measurement results of gate oxide film thicknesses before and after removing deposits by the mixed solution of HCl and H_2O_2, similarly to those in FIG. 6A. As shown in the figure, when the mixed solution of HCl and H_2O_2 is used as a washing solution, the same effects as those of the mixed

solution of H_2SO_4 and H_2O_2 are provided.

According to these results obtained by the washing using the mixed solution of H_2SO_4 and H_2O_2 and the washing using the mixed solution of HCl and H_2O_2, it is considered that water and carbon, which are contained in the air and are liable to be dissolved in or react with sulfuric acid (H_2SO_4) or hydrochloric acid (HCl), are attached to the surface of the gate oxide film to increase the apparent thickness of the gate oxide film. Therefore, any washing solution can be used provided that it can remove water and carbon from the surface of the oxide film.

In the embodiments described above, the gate oxide film 8 is formed through wet oxidation by a thermal CVD method. However, it is confirmed that the same effects as those in the embodiments described above were provided even when the gate oxide film was formed by other methods such as dry oxidation and plasma CVD method. The present invention can be applied to gate oxide films formed by various methods. In the second embodiment, although the apparent thickness of the gate oxide film is approximated by the formula (2), it can be approximated by other formulas (for instance, approximate formula using logarithm).

In the embodiments described above, the thickness of the gate oxide film is in a range of approximately 90Å to 110Å. However, the present invention is especially effective when the thickness of the gate oxide film is less than approximately 100 Å. The thinner the oxide film is, the more the rate of change-variations in the thickness is prominent. Therefore, in such a case, the thickness control according to the present

invention is very effective to measure the real thickness precisely. It is apparent that the present invention can be applied to the gate oxide film more than 100 Å in thickness as well.

While the present invention has been shown and described with reference to the foregoing preferred embodiments, it will be apparent to those skilled in the art that changes in form and detail may be made therein without departing from the scope of the invention as defined in the appended claims.

What is claimed is:

1. A method for measuring a thickness of an oxide film, comprising:

forming an oxide film on a substrate;

controlling a left period of time for leaving the oxide film from the formation of the oxide film to measurement of a thickness of the oxide film; and

measuring the thickness of the oxide film by irradiating the oxide film with light, in accordance with the left period of time.

2. The method of claim 1, further comprising correcting the thickness of the oxide film, which is measured when the left period of time is elapsed from the formation of the oxide film, based on the left period of time to obtain a real thickness of the oxide film.

3. The method of claim 2, wherein the thickness of the oxide film is corrected by a formula of:

$y = a \cdot \ln(t) + b$

in which t is the left period of time from the formation of the oxide film to the measurement of the thickness, y is the thickness of the oxide film measured when the left period of time is elapsed, a is a constant determined based on atmosphere around the oxide film, and b is the real thickness of the oxide film.

4. The method of claim 1, wherein the thickness of the oxide

film is measured within the left period of time to include a change variation T in thickness that is produced in accordance with the left period of time and satisfies a formula of:

$$\sqrt{S^2 + T^2} \leq U$$

in which S is a variation in thickness that is produced when the oxide film is formed, and U is an allowable latitude in the thickness of the oxide film.

5. A method for measuring a thickness of an oxide film, comprising:

forming an oxide film on a substrate;

washing a surface of the oxide film; and

measuring a thickness of the oxide film by irradiating the oxide film with light.

6. The method of claim 5, wherein the surface of the oxide film is washed using a solution containing at least one of H_2SO_4 and HCl.

7. The method of claim 6, wherein the solution is one of a mixed solution of H_2SO_4 and H_2O_2 and a mixed solution of HCl and H_2O_2.

8. The method of claim 5, further comprising

controlling a left period of time for leaving the oxide film from the washing of the surface of the oxide film to the measurement of the thickness; and

measuring the thickness of the oxide film in accordance with the left period of time.

9. The method of claim 8, further comprising correcting the thickness of the oxide film, which is measured when the left period of time is elapsed from the washing of the oxide film, based on the left period of time to obtain a real thickness of the oxide film.

10. The method of claim 9, wherein the thickness of the oxide film is corrected by a formula of:

$$y = a \cdot \ln(t) + b$$

in which t is the left period of time from the washing of the oxide film to the measurement of the thickness, y is the thickness of the oxide film measured when the left period of time is elapsed, a is a constant determined based on atmosphere around the oxide film, and b is the real thickness of the oxide film.

11. The method of claim 8, wherein the thickness of the oxide film is measured within the left period of time from the washing of the surface of the oxide film to include a change variation T in thickness that is produced in accordance with the left period of time and satisfies a formula of:

$$\sqrt{S^2 + T^2} \leq U$$

in which S is a variation in thickness that is produced when the oxide film is formed, and U is an allowable latitude in the thickness of the oxide film.

12. A method for manufacturing a semiconductor device, comprising:

forming on oxide film;

measuring a thickness of the oxide film in accordance with a left period of time for leaving the oxide film from the formation of the oxide film;

determining whether the thickness of the oxide film falls in a desirable range; and

performing a succeeding step for manufacturing the semiconductor device when the thickness of the oxide film falls in the desirable range.

13. The method of claim 12, further comprising correcting the thickness of the oxide film, which is measured when the left period of time is elapsed from the formation of the oxide film, to obtain a real thickness of the oxide film, wherein:

the succeeding step is performed when the corrected thickness falls in the desirable range.

14. The method of claim 13, wherein the thickness of the oxide film is corrected by a formula of:

$y = a \cdot \ln(t) + b$

in which t is the left period of time elapsed from the formation of the oxide film to the measurement of the thickness, y is the thickness of the oxide film measured when the left period of time is elapsed, a is a constant determined based on atmosphere

around the oxide film, and b is the real thickness of the oxide film.

15. The method of claim 12, wherein the thickness of the oxide film is measured within the left period of time to include a change variation T in thickness that is produced in accordance with the left period of time and satisfies a formula of:

$$\sqrt{S^2 + T^2} \leq U$$

in which S is a variation in thickness that is produced when the oxide film is formed, and U is an allowable latitude in the thickness of the oxide film.

16. A method for manufacturing a semiconductor device, comprising:

forming an oxide film;

washing a surface of the oxide film;

measuring a thickness of the oxide film by irradiating the oxide film with light;

determining whether the thickness of the oxide film falls in a desirable range; and

performing a succeeding step for manufacturing the semiconductor device when the thickness of the oxide film falls in the desirable range.

17. The method of claim 16, wherein the surface of the oxide film is washed using a solution containing at least one of H_2SO_4 and HCl.

18. The method of claim 17, wherein the solution is one of a mixed solution of H_2SO_4 and H_2O_2 and a mixed solution of HCl and H_2O_2.

19. The method of claim 16, further comprising controlling a left period of time for leaving the oxide film from the washing of the surface of the oxide film to the measurement of the thickness, wherein:

the thickness of the oxide film is measured in accordance with the left period of time.

20. The method of claim 19, further comprising correcting the thickness of the oxide film, which is measured when the left period of time is elapsed from the washing of the oxide film, based on the left period of time to obtain a real thickness of the oxide film.

21. The method of claim 20, wherein the thickness of the oxide film is corrected by a formula of:

$$y = a \cdot \ln(t) + b$$

in which t is the left period of time elapsed from the washing of the oxide film to the measurement of the thickness, y is the thickness of the oxide film measured when the left period of time is elapsed, a is a constant determined based on atmosphere around the oxide film, and b is the real thickness of the oxide film.

22. The method of claim 20, wherein the thickness of the oxide film is measured within the left period of time from the washing of the surface of the oxide film to include a change variation T in thickness that is produced in accordance with the left period of time and satisfies a formula of:

$$\sqrt{S^2 + T^2} \leq U$$

in which S is a variation in thickness that is produced when the oxide film is formed, and U is an allowable latitude in the thickness of the oxide film.

ABSTRACT OF THE DISCLOSURE

In a process of manufacturing a semiconductor device, after a gate oxide film is formed, a thickness of the gate oxide film is measured by controlling a left period of time from the formation of the gate oxide film to the measurement. Accordingly, the thickness of the gate oxide film can be measured accurately.

FIG. 1A

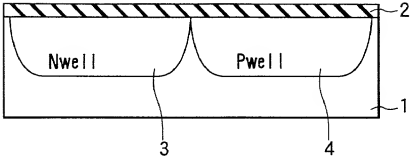


FIG. 1B

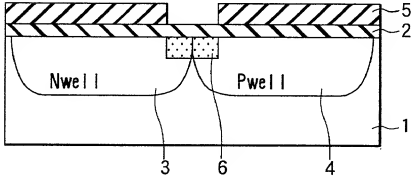


FIG. 1C

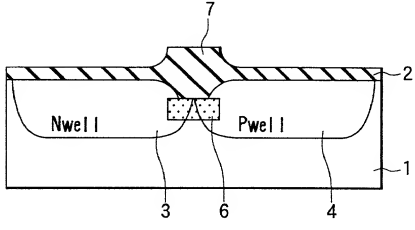


FIG. 2A

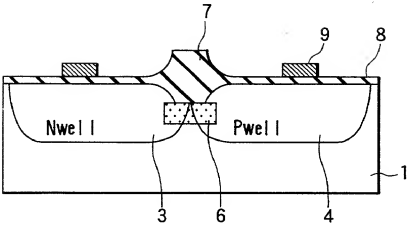


FIG. 2B

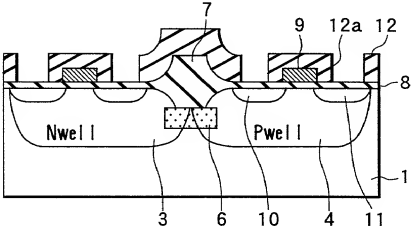


FIG. 2C

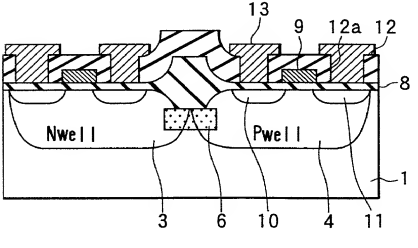


FIG. 3

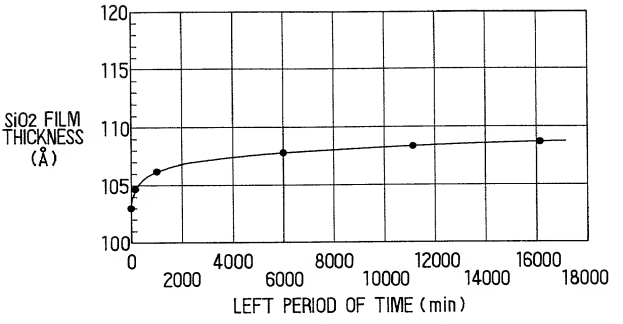

SiO2 FILM THICKNESS (Å)
120
115
110
105
100
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
LEFT PERIOD OF TIME (min)

FIG. 4

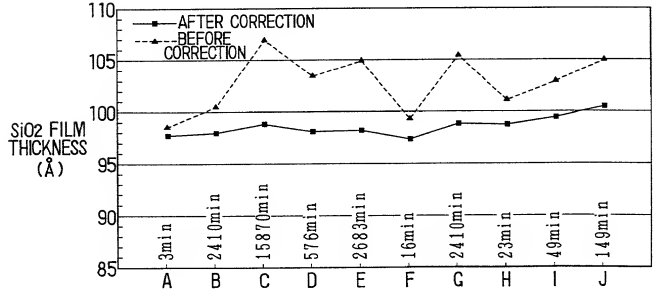

AFTER CORRECTION
BEFORE CORRECTION
SiO2 FILM THICKNESS (Å)
110
105
100
95
90
85
3min
2410min
15870min
576min
2683min
16min
2410min
23min
49min
149min
A
B
C
D
E
F
G
H
I
J

FIG. 5

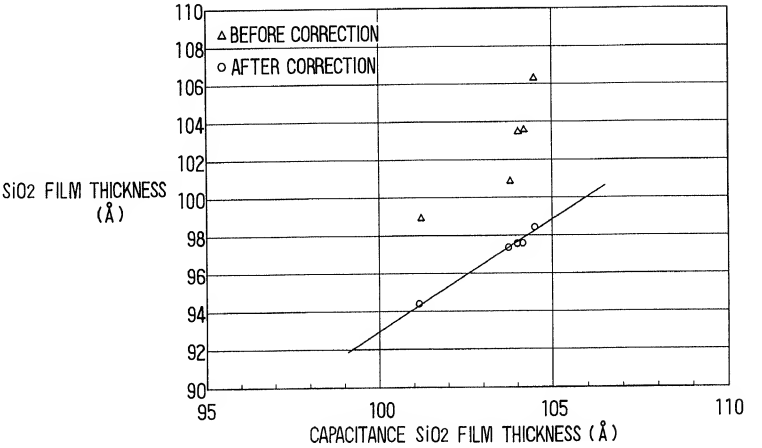


FIG. 6A

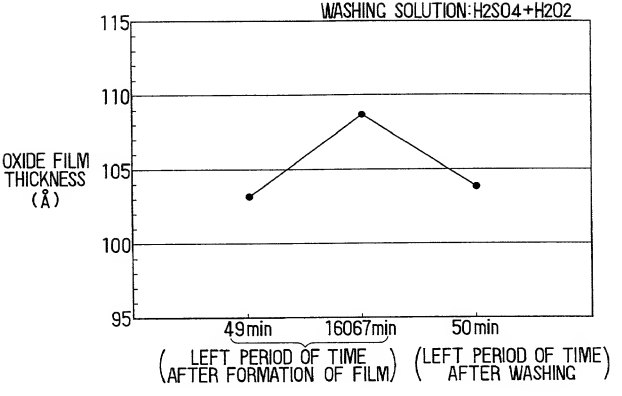
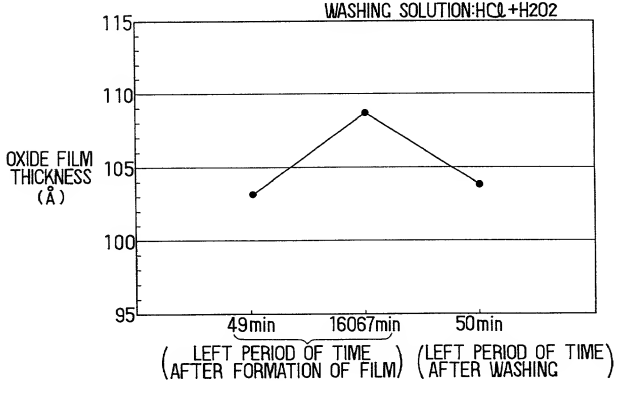

WASHING SOLUTION:H2SO4+H2O2
115
110
105
100
95
OXIDE FILM THICKNESS (Å)
49min
16067min
50min
(LEFT PERIOD OF TIME AFTER FORMATION OF FILM)
(LEFT PERIOD OF TIME AFTER WASHING)

FIG. 6B


WASHING SOLUTION:HCl+H2O2
115
110
105
100
95
OXIDE FILM THICKNESS (Å)
49min
16067min
50min
(LEFT PERIOD OF TIME AFTER FORMATION OF FILM)
(LEFT PERIOD OF TIME AFTER WASHING)

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Declaration and Power of Attorney for Patent Application
特許出願宣誓書及び委任状
Japanese Language Declaration
日本語宣言書

下記の氏名の発明者として、私は以下の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name.

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者(下記の氏名が一つの場合)もしくは最初かつ共同発明者であると（下記の名称が複数の場合）信じています。

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

METHOD FOR MEASURING THICKNESS OF OXIDE FILM

上記発明の明細書(下記の欄で×印がついていない場合は、本書に添付)は、

the specification of which is attached hereto unless the following box is checked:

☐ _____に提出され、米国出願番号または特許協力条約国際出願番号を _____とし、(該当する場合)_____に訂正されました。

☐ was filed on_____ as United States Application Number or PCT International Application Number_____ and was amended on _____ (if applicable).

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

私は、連邦規則法典第３７編第１条５６項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

私は、米国法典第３５編１１９条(a)-(d)項又は３６５条(b)項に基き下記の、米国以外の国の少なくとも一ヵ国を指定している特許協力条約３６５(a)項に基く国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United States Code, Section 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Japanese Language Declaration
(日本語宣言書)

Prior Foreign Application(s) 外国での先行出願				Priority Not Claimed (優先権主張なし)
1.	11-203562	Japan	16/July/1999	☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
2.				☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
3.				☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
4.				☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
5.				☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
6.				☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
7.				☐
	(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	

☐ Additional Foreign Application(s) is(are) listed on the attached sheet.

私は、第３５編米国法典１１９条(e)項に基いて下記の米国特許出願規定に記載された権利をここに主張いたします。

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

(Application No.) (出願番号)	(Filing Date) (出願日)

(Application No.) (出願番号)	(Filing Date) (出願日)

私は、下記の米国法典第３５編１２０条に基いて下記の米国特許出願に記載された権利、又は米国を指定している特許協力条約３６５条(c)に基く権利をここに主張します。また、本出願の各請求範囲の内容が米国法典第３５編１１２条第１項又は特許協力条約で規定された方法で先行する米国特許出願に開示されていない限り、その先行米国出願書提出日以降で本出願書の日本国内または特許協力条約国際提出日までの期間中に入手された、連邦規則法典第３７編１条５６項で定義された特許資格の有無に関する重要な情報について開示義務があることを認識しています。

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of application.

Application No. (出願番号)	Filing Date (出願日)

Status : Patented, Pending, Abandoned (現況) (特許許可済)、 (係属中)、 (放棄済)

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Japanese Language Declaration
(日本語宣言書)

私は、私自身の知識に基いて本宣言書中で私が行う表明が真実であり、かつ私の入手した情報と私の信じるところに基く表明が全て真実であると信じていること、さらに故意になされた虚偽の表明及びそれと同等の行為は米国法典第１８編第１００１条に基き、罰金または拘禁、もしくはその両方により処罰されること、そしてそのような故意による虚偽の声明を行えば、出願した、又は既に許可された特許の有効性が失われることを認識し、よってここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

委任状： 私は下記の発明者として、本出願に関する一切の手続を米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。(弁護士、または代理人の氏名及び登録番号を明記のこと)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith (list name and registration number)

David G. Posz, Reg. No. 37701 of LAW OFFICE OF DAVID G. POSZ, who is a registered Patent Attorney.

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直接電話連絡先 (名前及び電話番号) : Direct Telephone Calls to (name and telephone number)
David G. Posz, Esq., (202) 220-3105

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国籍 (Citizenship) Japanese	
私書箱 (Post Office Address) c/o DENSO CORPORATION, 1-1, Showa-cho, Kariya-city, Aichi-pref., 448-8661 JAPAN	

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国籍 (Citizenship) Japanese	
私書箱 (Post Office Address) c/o DENSO CORPORATION, 1-1, Showa-cho, Kariya-city, Aichi-pref., 448-8661 JAPAN	

☒ Additional Inventor(s) is (are) listed on the attached sheet which is incorporated herein by reference.

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Japanese Language Declaration
(日本語宣言書)

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発明者の署名 (Inventor' s Signature) Hiroshi Otsuki
日付 (Date) July 6, 2000
住所 (Residence) Okazaki-city, Japan
国籍 (Citizenship) Japanese
私書箱 (Post Office Address) c/o DENSO CORPORATION, 1-1, Showa-cho, Kariya-city, Aichi-pref., 448-8661 JAPAN

第四共同発明者(Full name of fourth joint inventor)
発明者の署名 (Inventor' s Signature)
日付 (Date)
住所 (Residence)
国籍 (Citizenship)
私書箱 (Post Office Address)

第五共同発明者 (Full name of fifth joint inventor)
発明者の署名 (Inventor' s Signature)
日付 (Date)
住所 (Residence)
国籍 (Citizenship)
私書箱 (Post Office Address)

第六共同発明者 (Full name of sixth joint inventor)
発明者の署名 (Inventor' s Signature)
日付 (Date)
住所 (Residence)
国籍 (Citizenship)
私書箱 (Post Office Address)